

Summary of Georgia's Experience with Stone Matrix Asphalt Mixes

Abstract

Stone matrix asphalt (SMA) is a gap-graded mix which contains a high concentration of coarse aggregate, thereby maximizing stone-to-stone contact in the mix and providing an efficient network for load distribution. The coarse aggregate particles are held together by a rich matrix of mineral filler, fiber, and polymer in a thick asphalt film.

SMA has proven very successful in Europe, and American asphalt professionals were first introduced to the mix on a European Asphalt Study Tour in 1990.

As a result of the tour, the Georgia Department of Transportation (GDOT) became interested in using SMA mixes on the Georgia road system. GDOT developed two research projects to evaluate the performance of SMA versus that of conventional mixes as (1) an intermediate and wearing course under heavy truck loads, and (2) an overlay for portland cement concrete pavements. A test section was constructed for each research project in 1991 and 1992, respectively, and the degree of pavement rutting and distress was monitored periodically.

Based on a combination of GDOT and European experience, SMA has proven to have the following intrinsic benefits:

- 30-40% less rutting than standard mixes
- 3 to 5 times greater fatigue life in laboratory experiments
- 30-40% longer service life (in Europe)
- lower annualized cost

As a result of several years of SMA research and experience, GDOT has expanded the use of SMA as a dense-graded surface mix for Georgia interstate pavements.

I. Introduction

In the early 1960's, the European asphalt industry recognized a critical need for pavements which would be resistant to rutting, abrasion, and various pavement distresses induced by heavy traffic and studded tires. To address this need, roadway pavement contractors developed SMA. SMA is a gap-graded mix containing a high concentration of coarse aggregate, which maximizes stone-to-stone contact and provides an efficient network for load distribution. The coarse aggregate particles are held together by a rich matrix of mineral filler, fiber, and polymer in a thick asphalt film.

SMA proved very successful in Germany, and SMA use continued even after the elimination of studded tire use in Germany. German road authorities eventually included SMA as a standardized mixture class in their pavement specifications. SMA was initially adopted from the Germans by Sweden and Denmark, but it is now used extensively in Norway, Finland, Austria, France, Switzerland, and the Netherlands as well. (1)

In 1989 John Gray, President of the National Asphalt Pavement Association (NAPA), suggested that an investigation of European pavement technology might enhance pavement research being conducted in the United States. He proposed a European tour project to review and evaluate European pavements and asphalt technology. This

idea was embraced by the asphalt industry, and in September 1990, a contingent of asphalt experts and industry representatives embarked on a 14-day European Asphalt Study Tour. In a subsequent report, the group concluded that European engineers had produced pavements superior to pavements in the U.S. by using innovative techniques, equipment, and materials in their pavement designs and construction. One of the highlights of this trip was the discovery of European success with SMA pavements.

As a result of the tour, GDOT became interested in the use of stone matrix asphalt, and in December, 1990, began to research the viability of using SMA mixes on the Georgia road system. Since SMA technology was new to the United States, GDOT sought technical assistance from other organizations gaining SMA experience. Proposed materials were gathered and sent to these agencies for their testing, evaluation, and recommendations. Agencies offering technical assistance to GDOT included Laxa Bruk in Gothenburg, Sweden, in cooperation with Fiberand Corporation; the Texas Transportation Institute at Texas A & M University; the Turner-Fairbanks Highway Research Center; and the National Center for Asphalt Technology (NCAT).

II. Research Project No. 9102

The objectives of GDOT's first SMA research project, No. 9102, were (1) to evaluate the performance of SMA asphalt under the stresses of heavy truck loadings, and (2) to compare the performance of SMA to the performance of conventional GDOT mixes. In 1991, various combinations of SMA and standard mixes were placed in a 2.5-mile, high traffic volume test section on Interstate 85 northeast of Atlanta. SMA was evaluated as both an intermediate and surface course. The location on I-85 in northeast Georgia was selected due to its average daily traffic (ADT) of 35,000, including 40% trucks. This traffic roughly equals 2 million equivalent single axle loads (ESALs) per year.

A. Mix Design

The 50-blow Marshall Mix Design procedure was chosen as the design standard, since this procedure is used in the design of European SMA. Coarse and fine SMA mixes were designed for use as intermediate layers and wearing courses, respectively.

Two distinctly different aggregates were selected for the wearing course. A granite gneiss with an abrasion value of 35% was used, since this abrasion value is typical of aggregates most commonly used in Georgia hot mix asphalt (HMA). A gneiss-amphibolite with an abrasion value of 20% was also selected since its properties closely resemble those of aggregates typically used in European SMA. An AC-30 asphalt cement was used in the mixtures. The asphalt cement was modified with a low-density polyethylene thermoplastic to stiffen the binder, and the asphalt cement achieved a viscosity of approximately 97×10^4 cP. Mineral filler, mineral fiber, and hydrated lime were also added to the mixtures to reinforce the matrix and stabilize the thicker asphalt film.

B. Production

In order to simulate European production techniques, a batch plant was employed. Three major modifications were made to the existing plant configuration. (1) To introduce the mineral filler, a hopper was added to the side of the plant and treated as a

separate material bin. Mineral filler was blown into this hopper, then proportioned into the mix via the plant weigh hopper. Mineral fiber was added manually through an opening cut into the rear of the weigh hopper. The fiber had been packaged in 25-lb. bags, and only one bag was required per batch. (2) Asphalt cement was routed from the storage tanks into a trailer-mounted blending unit. This unit added the polyethylene thermoplastic modifier, which was sheared into the asphalt cement. After blending, the modified asphalt was dispersed with the aggregate during mix production. (3) Due to the stiffness of the modified binder and the presence of mineral fibers, the mixing temperature was increased to 325°F to provide greater workability. A dry mixing time of 14 seconds and a wet mixing time of 35 seconds were required to ensure proper distribution of the mineral fiber and adequate coating of aggregates.

C. Construction/Materials Evaluation

A one-mile portion of the test section was milled and inlaid with approximately 2 in. of the SMA intermediate course. The remainder of the test section consisted of two variations of an SMA wearing course placed at about a 1-1/2 in. thickness. The test section layout is shown in Figure 1. The mix was placed with a paver equipped with a 40 ft. ski and electronic grade and slope controls. Compaction was accomplished using a 56 in. drum vibratory roller and an 8-12 ton static tandem roller containing ballast.

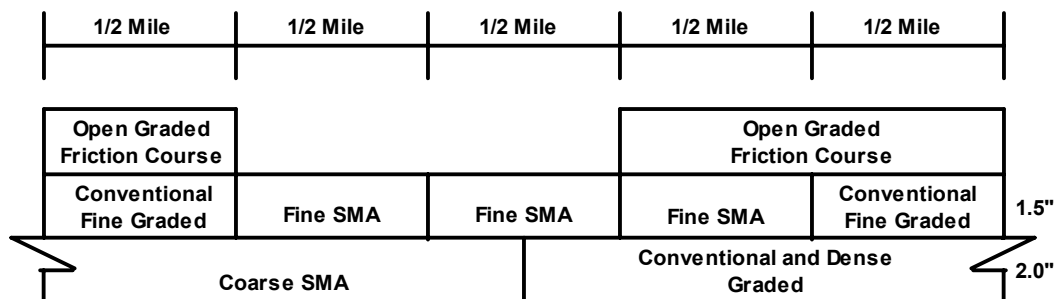


Figure 1. Test Section Layout: GDOT Research Project 9102

Initial field and laboratory testing indicated that the property values of the in-place mix fell within the range expected. Average in-place SMA properties obtained from the field and laboratory tests are shown in Table 1.

TABLE 1. Average In-place SMA Properties: Research Project 9102

Property	Coarse SMA	Fine SMA
Air Voids (%)	5	6.7
Tensile Strength Retained (%)	99.8	84
Loaded Wheel Test (mm/8000 cycles)*	3.2	1.4

*1 mm = 0.04 in.

III. Analysis of Rutting and Friction Properties

Following the construction of the I-85 test section in 1991, GDOT began to monitor the degree of rutting in both the fine SMA and conventional mixes used in the test section. The results of rutting measurements conducted between 1993 and 1995 are shown in Table 2. These results verify earlier measurements made for the same mixes using the Georgia Loaded Wheel Tester, clearly indicating that significantly less rutting occurs when SMA mixes are used in place of conventional mixes. This reduction in rutting also confirms European experience with SMA mixes.

TABLE 2. Rutting of Fine SMA vs. Standard Hot Mix: I-85 Test Section

Year	SMA (mm)*	Standard (mm)
1993	0	3
1994	2.3	5.3
1995	2.5	6.8

*1 mm = 0.04 in.

GDOT also used the I-85 test section to monitor the friction provided by SMA mixes. As shown in Table 3, the friction provided by the SMA mixes improved between 1991 and 1996. GDOT was concerned that the thick asphalt film characteristic of the fine SMA would reduce frictional properties needed for traversing vehicles; however, the results obtained indicate that the thicker film wears quickly at the surface and will indeed provide good friction. The thicker film also increases mix durability and fatigue life.

TABLE 3. Friction Values for Fine SMA Mix: I-85 Test Section

Friction Number	
Date	Number
11/91	42
2/92	50
1/96	50

IV. Research Project No. 9202

In 1992, a second research project, No. 9202, was begun to evaluate the use of SMA as an overlay for portland cement concrete (PCC) pavements. A test section was placed on Interstate 75 south of Atlanta in Henry County to determine if the coarseness of the SMA mixes might deter rutting and other distresses normally associated with flexible overlays.

The location for this project was chosen because of its high ADT (47,000) and high percentage of truck traffic (21%). The test sections were placed in the outside travel lane, which typically accommodates most of the truck traffic.

As in Research Project 9102, the 50-blow Marshall design method was used. Granite gneiss-amphibolite was selected as the aggregate for this project, and the abrasion value of the aggregate was 37%. Styrene butadiene (SB) was used as an asphalt modifier, and cellulose fiber was included in the mix, along with hydrated lime and mineral filler.

A. Production

A double-barrel drum plant was used for the production of the SMA mixes. However, no more than 50 tons of mix could be stored in the silo, as any tonnage exceeding this amount hampered the mix discharge. As with the batch plant in the first research project, modifications to the drum plant were necessary to ensure that the cellulose fiber, mineral filler, and modified AC were properly introduced to the mixture.

Cellulose fibers were introduced by a blower which dispersed them with the aggregate before the asphalt cement was introduced. Adding fibers in the outer portion of the double drum prevented them from being caught in the airstream. The fibers were blown into the drum at a rate of 15 lb./minute. They were introduced at about the same time as the hydrated lime. GDOT helped pioneer this method of fiber introduction, and this project marked one of the first times the method had been used effectively.

Asphalt cement storage tanks were not used. The modified cement was premixed at the terminal and pumped directly from the tanker trucks into mix production. Mineral filler was augered into the drum from a separate silo, and it entered the drum at about the same time as the baghouse dust, hydrated lime, and cellulose fibers.

B. Construction/Materials Evaluation

A ½-mile test section was milled and inlaid with approximately 2 in. of coarse SMA. The mix was placed with a paver equipped with dual inboard skis and electronic guide and slope controls. Rolling was performed by two double drum vibratory rollers. The ½-mile section of coarse SMA was overlaid with a fine SMA wearing course. Another ½-mile of fine SMA was placed as an overlay on milled conventional asphaltic concrete. The test section layout is shown in Figure 2.

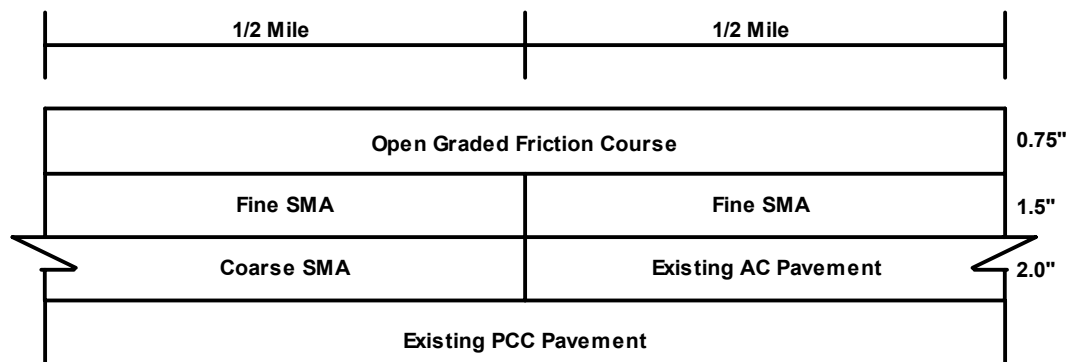


Figure 2. Test Section Layout: GDOT Research Project 9202

Initial field and laboratory testing indicated that the property values of the in-place mix fell within the expected range, as in the first research project. Average in-place SMA properties obtained from the field and laboratory tests are shown in Table 4.

TABLE 4. Average In-place SMA Properties: Research Project 9202

Property	Coarse SMA	Fine SMA
Air Voids (%)	3.6	5.7
Tensile Strength Retained (%)	82.7	98.7
Loaded Wheel Test (mm/8000 cycles)	3*	3.2

*Composite sample of Fine over Coarse SMA

V. Mix Optimization Research

In order to learn more about methods of enhancing SMA performance, GDOT studied mix optimization techniques for SMA in a joint research study with Georgia Tech. Practical techniques were sought that could be implemented in the SMA mixes used for upcoming projects.

Research conducted at Georgia Tech showed that (1) GDOT fine SMA mixes undergo at least 30% to 40% less rutting than a typical GDOT dense-graded surface mix, and (2) these fine SMA mixes typically have a fatigue life of 3 to 5 times that of a conventional surface mix. Rutting was measured with the Georgia Loaded Wheel Tester, and a complex relationship was found between the degree of rutting and two other parameters, the 3:1 flatness/elongation ratio of the aggregate and the L.A. abrasion value. Under favorable conditions for the flatness/elongation ratio, the abrasion value can be as high as 45, and under favorable conditions for the abrasion value, the flatness/elongation ratio can be as high as 45%. (2) As the abrasion value decreases, the corresponding flatness/elongation ratio may increase. Corresponding L.A. abrasion values and flatness/elongation ratios for the SMA mixes tested are shown in Table 5.

TABLE 5. Relationship of L.A. Abrasion Value to Flatness/Elongation Ratio

L.A. Abrasion Value	F/E Ratio (3:1)
≤ 45	≤ 20
≤ 40	21-25
≤ 35	26-35
≤ 30	36-40
≤ 25	41-45

Due to concerns about regional variations in the abrasion values of aggregates used in SMA mixes, GDOT conducted a study of the breakdown of aggregates in fine SMA

mixes used in the test sections constructed for Research Projects 9102 (I-85) and 9202 (I-75). In the I-85 test section, core samples were taken from two fine SMA sections, each with a different aggregate source (Buford and Ruby, respectively). In the I-75 test section, core samples were taken from fine SMA with a third aggregate source (Mt. View). The study results indicate that aggregate breakdown in all of the mixes used is small, and does not vary significantly from region to region. These results are shown in Table 6.

**TABLE 6. Aggregate Breakdown of Fine SMA Mixes:
Test Section Gradation Results (% Passing)**

Sieve Size	I-75: Mt. View		I-85: Buford Fine		I-85: Ruby Fine	
	1992	1994	1991	1994	1991	1994
19 mm	100	100	100	100	100	100
12.5 mm	99	98	99	99	99	100
9.5 mm	79	80	88	85	85	85
4.75 mm	40	41	48	46	41	38
2.36 mm	25	25	31	30	26	25
0.3 mm	15	15	20	20	16	16
0.075 mm	8	8	10	10	10	10

The study also indicated that important production cost savings could be realized if the aggregate quality requirements for SMA mixes were relaxed, but the performance of the mixes would not be significantly reduced. In Europe, aggregate quality requirements for SMA mixes are typically very stringent.

Based on this research, GDOT implemented use of aggregates which have no more than 45% abrasion loss and which have no more than 20% flat and elongated particles when measured at the 3:1 ratio.

VI. I-95 Projects

The corridor of I-95 through coastal Georgia from South Carolina to the Florida state line supports very heavy traffic volumes. The successful performance of SMA in the GDOT test sections, along with the mix optimization techniques developed, gave GDOT the confidence to let to contract three widening/resurfacing projects on I-95 near Savannah using SMA mixes. The projects, let between October 1992 and July 1994, extend from the South Carolina border to State Route 144, a distance of 27.5 miles.

A total SMA tonnage of nearly 195,000 tons was laid, including both fine and coarse SMA mixes. GDOT plans to ultimately widen/resurface the entire I-95 corridor from South Carolina to the Florida state line, a distance of approximately 120 mi., and to use SMA mixes throughout the corridor.

VII. HOV Lane Project

Encouraged by the success of the I-95 projects, GDOT launched another major SMA resurfacing project in downtown Atlanta: the installation of High Occupancy Vehicle lanes on Interstates 75 and 85 inside I-285. These special "Express Lanes" provide 24-hour service for buses and vehicles with two or more occupants. The lanes increased downtown traffic capacity by 20%, and no additional right-of-way acquisition or new lane construction was necessary. The lanes were provided primarily to improve air quality in the metro Atlanta area. The \$41 million project covered approximately 30 mi. (330 lane-mi.) of milling and inlay resurfacing and included the placement of nearly 200,000 tons of SMA. This project, possibly the largest tonnage SMA project in the world, was let to contract in July, 1995, and was completed in May, 1996. The project work was largely performed at night, under adverse traffic conditions, with construction zone traffic volumes averaging 300,000 vehicles per day.

Contractors for this work incorporated a material transfer device in the laydown operation to maintain continuity of operations, improve mixture consistency, and to provide a smooth riding surface. These efforts contributed to making this project one of the smoothest SMA projects placed to date. Average Maysmeter values for ride quality were only 380 mm (15 in.) per mile. This work has also encouraged local asphalt suppliers to equip their facilities for terminal blending of polymer modified asphalt.

VIII. Annualized Cost Comparison: SMA vs. Conventional Hot Mix Asphalt

A life-cycle cost analysis was conducted which compared SMA with conventional hot mix asphalt. The roadway selected for this analysis consisted of four 12 ft. wide lanes, including inside shoulder widths of 10 ft. and outside shoulder widths of 12 ft. The analysis used rehabilitation intervals of 7.5 years for conventional mixes, and 10 years for SMA. This comparison corresponds to the 30-40% expected increase in SMA pavement life that is exhibited in Europe. A 30-year life cycle period was used to obtain a base period for the two mix types. The results of the analysis are shown in Table 7.

TABLE 7. Annualized Cost Comparison: SMA vs. Standard Asphalt

Pavement Type	Rehab. Intervals (Yrs.)	Annual. Cost (\$)
Standard	7.5	79,532
SMA	10	50,095

IX. SMA Specification Changes

Since GDOT's initial experiments with SMA mixes in 1991, several revisions to specifications governing SMA mixes have been made. Specifications for fibers, polymer modifiers, mineral fillers, and aggregate gradations in SMA mixes have been revised as described below.

Fibers. GDOT specified a longer fiber length to reflect fiber production in USA and enhance reinforcement network in the asphalt binder film.

Polymer Modifiers. In order to provide a stiff yet durable asphalt binder, GDOT implemented the use of Superpave PG 76-22 asphalt binder modified with polymers for use in all SMA mixes.

Mineral Filler. Tolerances have been increased to more closely reflect current production. The mineral filler is included in tests of the asphalt mortar.

Gradations for Job Mix Formulas. The new requirements significantly coarsen SMA mixes. For example, the allowable percent passing the No. 4 sieve for fine SMA mixes was decreased from 28-50% to 25-32%. This coarsening of the mixes enhances the stone-to-stone contact of the mix and provides a more efficient load distribution network.

X. Current Research

GDOT is participating in the Accelerated Loading Pavement Study, a national pooled-fund study being conducted by NCAT at a test track near Opelika, Alabama. The test track consists of 26 HMA test sections, and 10 million ESALs are to be applied to the track over a two year period, which is to end in October 2002. The performance of these sections is being periodically evaluated during the test period and the results provided to participants. Improved methods of predicting performance are being evaluated so that HMA mixes using various materials can be optimized.

One comparison being conducted in the test sections assigned to GDOT is between SMA and Superpave Level D mix, which is a polymer-modified asphalt. SMA is normally used where ADT exceeds 50,000, but Superpave Level D may be a viable alternative. With approximately 25% of the testing remaining, no significant difference in performance has been observed between the mixes.

XI. Conclusions

The GDOT has adopted SMA technology for its sound theory and for its practical approach to producing highly durable and rut-resistant pavements. Based on a combination of GDOT and European experience, SMA has proven to have the following intrinsic benefits:

- 30-40% less rutting than standard mixes
- 3 to 5 times greater fatigue life in laboratory experiments
- 30-40% longer service life (in Europe)
- lower annualized cost

As a result of several years of research and experience with SMA, GDOT has expanded the use of SMA as a dense-graded surface mix for Georgia interstate pavements.

XII. References

1. Watson, Donald, and Jared, David. Stone Matrix Asphalt: Georgia's Experience. Georgia Department of Transportation, 1995.
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